UTILIZATION OF ERTS-1 DATA IN NORTH CAROLINA

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16. Abstract

A wide range of potential uses for ERTS-1 imagery is described. Special emphasis has been placed upon studies in the Coastal Plain of North Carolina. Soil groups, water quality, and suspended sediment patterns in estuaries and offshore have been studied. A phytoplankton bloom has possibly been detected. The usefulness of the imagery in coastal landform surveys has been demonstrated as has its usefulness in monitoring developmental activity in the forests. Planners appear hesitant to use the imagery because of its small scale, but it is felt that as they become familiar with the imagery they will find it useful and time-saving for many purposes.

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1.0 Preface

The purpose of the investigation is to demonstrate the usefulness of the ERTS-1 imagery in geological evaluation, regional planning, forest management, and water management in North Carolina. Visual analysis of the imagery as well as color additive viewing is to be utilized in interpreting the imagery.

For the period covered by this report, both generalized and detailed study of the imagery have been undertaken, and agencies and persons probably interested in its use have been contacted.

Quality of the imagery as determined by cloud cover and sun angle greatly influence the novice's first impression of the imagery and the immediate conclusions regarding its potential usefulness in a given situation. Evaluation of selected imagery at a scale of 1:500,000 by a photogeology class demonstrates that the range of usefulness depends to a great extent upon the quality of the imagery, the location being studied, and the interest of the potential user in extracting data from the imagery. ERTS imagery is proving useful in studying the geomorphology and soils groups of the Coastal Plain. Detailed studies in forested regions have begun, and first efforts at assessing usefulness of the imagery for water quality have been undertaken also. Change detection, particularly along flood plains of the larger coastal rivers and in lowland areas being drained for forest production has proved feasible. Water-mass circulation in the estuaries and offshore North Carolina known to be tide- and wind-related can be studied on the ERTS imagery. In general, the investigators have attempted to give the imagery the widest possible distribution and to work with people and

agencies who appear to be potential users.

Criticisms from local planners fall into two categories: (1) scale and (2) inability to extract instantaneously and with little effort on their part, the information they need. The latter category is a criticism that can be overcome in part with education.

It is generally recommended that the procedures outlined in the proposal continue to be followed.

2.0 Introduction

This report describes the work accomplished under ERTS-A Data Investigation Contract NAS5-21732 during the period December-May, 1972-1973. The main thrust of the investigation during this period has been to acquaint the investigators further with the imagery, to develop the photographic techniques best suited for their situation, to bring to various local and state agencies the knowledge of the availability of the imagery, and to begin an educational process in its use. One conclusion that seems inescapable is that use of the imagery on a routine basis requires a very positive demonstration of the benefits of its use to a particular organization. The educational process necessary to achieve a good level of acceptance requires time.

2.1 Discussion

As with the first six months of the investigation, a considerable portion of the investigators' time has been spent acquainting appropriate state and regional agency personnel with the nature of the imagery, discussing their needs vis-a-vis the imagery, and developing photographic capabilities which will permit the investigators to respond to the agencies' needs in a short time frame.

Two composites of ERTS-1 photography for the State of North Carolina have been prepared by a student in a Graphics Arts class. Copies of these maps were sent with the Type I report for May. The maps have proved effective in showing the major cultural and physiographic features of North Carolina. The same student prepared a brochure about ERTS-1 imagery as part of a class exercise. Tear sheets from this project have also been submitted in an earlier report.

The University's publication, The University in Action, March, 1973, used as a lead story an article about ERTS-1 projects and in this article and another utilized ERTS-1 imagery to illustrate particular points. Copies of this publication accompany this report.

Projects continuing from the earlier report period or commenced early in the current report period include assessment of the use of ERTS-1 imagery in mapping forest types in northeastern North Carolina, use of ERTS-1 imagery in mapping land-use patterns and cropping activities in northeastern North Carolina, evaluation of ERTS-1 imagery in regional planning in Region J (Raleigh area), and evaluation of ERTS-1 imagery for geologic interpretations in the mountains of North Carolina. Water quality investigations in some of the larger rivers and in the sounds and estuaries are being pursued, chiefly through compilation of data already being collected by other agencies. A study of the ERTS-1 imagery as an aid in Level I land-use classification has been initiated for part of the New River drainage basin in northwestern North Carolina and in the Asheville-Buncombe County area. The former investigation is being undertaken by the local Soil Conservation Service Office in conjunction with a planning effort on their part. In the Asheville area the investigation is part of a larger land-use investigation and inventory undertaken by the Office of State Planning for the Appalachian Region; in addition, imagery has been made available to the Superintendent of the University's Mountain Horticultural Station. He will provide groundtruth about crops and land-use patterns.

Groundtruth data on water quality are being collected in the Wilmington area by students at Cape Fear Technical Institute and soil moisture data are being collected by personnel at the University's

Horticultural Crops Research Station at Castle Hayne. Sampling is taking place in experimental soybean and blueberry plots. Cloud cover has plagued this effort, although the April 27 overpass appears to have acquired a usable image for some of these studies. However, additional images and groundtruth data are necessary before any definitive conclusions can be made.

Automatic soil moisture recording devices have been reinstalled in fields at several of the University's Agricultural Experiment Stations across the Piedmont and Coastal Plain provinces of the state. Soil moisture data as well as information about the crop type and crop conditions will be available for these sites to support possible ERTS-1 imagery interpretation. This data will be collected from about May 1 through October.

A study of a recreational lake in the Greensboro area was begun during the last reporting period. The chief problem presented to the investigator, a graduate student in Forestry, was that available air photographs do not provide a suitable base map for planning purposes around the lake. Because of a diversity of scale and dates for the photography, the lake cannot be shown accurately. ERTS-1 imagery was enlarged and the transparencies projected. A map of better quality than presently available was constructed showing the boundaries of the lake at a scale of 1 inch = 1 mile. The synoptic overview provided by the ERTS-1 imagery also appears helpful in analyzing the air photography in conjunction with this project.

During the present reporting period considerable effort was placed upon using ERTS-1 imagery in evaluation of the Coastal Plain region of

North Carolina. Three major investigations were undertaken and are going on at the present time: (1) land-use study of parts of Jones, Craven, and Carteret Counties (Cape Lookout area) with emphasis upon the woodland types, the general soil types, and crop types; (2) geologic evaluation of the Wilmington test site and an area immediately around it; and (3) study of the sediment distribution patterns in Albemarle and Pamlico Sounds and offshore. The results of there investigation are described in Section 2.1.1, Significant Results. Acquisition of a color additive viewer and development of simple projection techniques utilizing the 70 mm negatives and a standard 3 x 4 inch slide projector have aided the first investigation.

Density slicing with 11 colors of ERTS-1 image 1205-15153 has given insight to land-use and vegetative patterns in the Cape Lookout area. Possible use of this and earlier images for wetlands mapping and mapping of drained areas is being investigated.

Water quality investigations in conjunction with the ERTS-1 program have been given an assist through the award of a research grant from the University of North Carolina Water Resources Research Institute in the amount of $12,000. This grant will provide funds to fly the University's multispectral camera in support of some ERTS-related water quality investigations.

2.1.1 Significant Results

(a) Geologic Interpretation of Coastal Plain

Use of ERTS-1 imagery has aided in refining interpretations of the sequence of events leading to the present geomorphology; images 1081-15262, 1170-15205, and 1134-15211 were used in the analysis. A copy of the

report of this investigation is attached as a separate. An abstract was forwarded with an earlier report.

(b) Land-use Study of the Cape Lookout Area

This area is an extension of the Wilmington test site. Ground checking of the area is currently going on, but density slicing, color additive viewing, as well as visual study of enlargements (up to about 1:80,000 scale) have enabled us to determine that the imagery will be useful in mapping soils at the group level, especially in areas that are nearly inaccessible. Spectral responses indirectly reflect differences in the organic content of the soils, and consequently their moisture-holding capacity. It is believed that the imagery will greatly speed up an evaluation of the Coastal Plain in the Hofmann Forest-Croatan Forest area. There is some indication, as yet unproved, that the different reflectances recorded by the imagery may be an indirect indication of the groundwater recharge pattern in this part of the Coastal Plain. The imagery is useful in selecting drill sites for subsurface investigations, although larger scale maps and air photographs must be used for precise location of the drill sites. The synoptic view given by the imagery serves to cause investigators to ask questions about relationships and to plan their activity somewhat more efficiently.

Quantitative or semiquantitative evaluation of the reflectances given by various open lands, woodlands, and cropped areas has not been undertaken, but a density slicing experiment suggests that some care must be exercised in applying absolute reflectance values to various features. Some operator interaction is necessary.

A little over a year ago a fire burned about 5,000 acres in Hofmann Forest. Enlargements of ERTS-1 imagery 1170-15205 made for this area

bring out differences in reflectances within the burn. At this time we do not know the causes of these differences, but they may be due to differences in vegetative cover developing on the burn, differences in soil types, or differences in the effect the fire had on the soil. The fire had temperature differences within it, and it has been suggested that these temperature differences have an areal distribution which is recorded in the soils and is therefore in the ERTS imagery. The investigation of the burned area is continuing in conjunction with the general study of the Hofmann Forest area.

(c) Sediment Distribution Pattern in Albemarle and Pamlico Sounds

This investigation relates the wind conditions to the pattern of suspended sediment within Albemarle and Pamlico Sounds and offshore. It has long been known that wind effects the current patterns within the sounds and that the water masses move in response to the wind. ERTS-1 images from fall and winter have been compared with weather conditions immediately preceeding the overpass and with tidal conditions at the time of an overpass. ERTS-1 image 1132-15092 is of particular interest because it shows the apparent effect of the Gulf Stream on the sediment transport. The winds on December 12 had been from the west and west-southwest, and the tide at the time of the overpass was about 0.8 through the ebb cycle. The Gulf Stream lies about 20 miles offsore at this point. The image shows the apparent transport of suspended materials northeastward 60 or 70 miles from Cape Hatteras. Other results from this investigation were outlined in a paper presented at the North Carolina Academy of Science meeting, April 27, a copy of which is attached. An abstract of this paper accompanied an earlier report.

Image 1205-15150 is believed to record the presence of a phytoplankton bloom in Albemarle Sound and in parts of Pamlico Sound. Although groundtruth observations are not available for this particular date, a continuing sampling program conducted in Albemarle Sound and in the Pamlico River by the University's Pamlico Marine Laboratory has shown the existence of a phytoplankton bloom from January to the time of the imaging. The bloom reportedly reached its maximum intensity in mid-February. The effects of the southwestward flowing winds on the water masses are also shown in this image. This aspect of the investigation shows the need for consideration of wind conditions in developing a sampling program in the sounds, and suggests that use of ERTS imagery by physical oceanographers studying the sounds can lead to better sampling procedures and more realistic mathematical models.

(d) Other

The effects of late November rains upon the floodplains of the lower Cape Fear River is apparent when images 1080-15203 and 1134-15211 are compared, particularly in bands 6 and 7. The required stream flow data necessary to relate stream flow and flooding to width of the zone of flooding have not been compiled, but this step seems quite feasible and useful.

An attempt at a Strahler Analysis of the Lumber River and Little Pee Dee River using image 1081-15262 at a 1:1 million-scale leads to several general conclusions:

(1) Detection of smaller streams depends greatly upon the presence or absence of a recognizable floodplain.

(2) Even in the case of some of the larger streams, the absence of a recognizable floodplain makes recognition of the stream difficult.

(3) There is a change in stream drainage pattern at the contact between the Black Creek and Tuscaloosa formation, the number of streams decreasing in the Tuscaloosa.

(4) The area of the state underlain by the Black Creek formation is more intensely farmed than is the area underlain by the Tuscaloosa formation.

Sediment influx into some of the major reservoirs of the state has been observed from ERTS-1 imagery and the capability of ERTS-1 imagery to provide information about sources of sediment was described at the NASA ERTS-1 Symposium in March. It appears from our observations that measurement of sediment concentration in the major reservoirs following major rains is possible utilizing the ERTS-1 imagery. Some groundtruth data exists for determining spectral response-sediment concentration relationships, but it has not been studied. Qualitatively such measurements can be made.

2.2 Future Program

The investigation will continue along the same general lines it has. Major emphasis will be in getting cooperators and other possible interested state and local governmental agencies to study the imagery and to work with it. We now have a sufficient amount of imagery for the Coastal Plain and parts of the Piedmont so that seasonal comparisons can be made.

Especial emphasis will be made to study crops and crop-related problems, water quality in the estuaries and the larger rivers, and reservoirs, and the forests. Man's impress upon the environment will come under scrutiny in that we will continue our efforts to have planning

organizations work with the imagery and to help us evaluate it. This will take time and effort as an educational process is required. As time permits, we will try to make or have made Level I land-use maps of the Asheville, Winston-Salem, Wilmington, and Raleigh areas.

A local study in the New River drainage basin is planned in an attempt to demonstrate the usefulness of enlargements and color additive viewing in making land-use inventories. This project will be undertaken with the cooperation of the local office of the Soil Conservation Service.

Geologic studies barely begun in the Piedmont and in the Asheville area will be pursued more vigorously than heretofore. We expect that the imagery may be useful in working in the Brevard zone.

A wetlands mapping project will be undertaken by personnel directly involved in the project. Once the techniques are sufficiently understood and the level of accuracy obtainable determined, efforts will be made to enlist the aid of the North Carolina Department of Natural and Economic Resources and the Soil Conservation Service in updating the existing wetlands map of the coastal region. Such a map could have an important role to play in legislation speaking to regulations of land use in the coastal zone.

One interesting problem being studied is the mapping of mosquito habitats. Test plots in the Cape Lookout area have been studied extensively, and mapping of the larger areas favorable for mosquito reproduction seems feasible on the basis of the associated marsh grasses. It is expected that we will work with personnel in the School of Biological and Agricultural Sciences in attacking this problem.

Forested areas in urbanized and unurbanized regions are being evaluated, and ERTS-1 imagery will be employed eventually in this study.

3.0 Conclusions

The regional uses of ERTS-1 imagery appear to be most fruitful. The scale, as noted before, acts as a hindrance in working with some of the smaller problems that concern local planners. Development of an understanding of the dynamics of the offshore area seems possible from the ERTS-1 imagery once a sufficient amount of imagery is available for different wind and tide conditions. For the larger rivers, floodplain mapping seems feasible, and the correlation of major rainfalls with extent of flooding seems possible for Coastal Plain rivers.

ERTS-1 imagery with its synoptic overview will permit rapid mapping of soils groups in inaccessible areas and will guide detailed mapping in places in the Coastal Plain. It is believed that the four band separation will provide clues to areal extent and importance of problem soils.

A considerable amount of education needs to be done to get regional and local planners and governmental officials to begin to apply ERTS-1 imagery to their problems.

4.0 Recommendations

It is generally recommended that the procedures outlined in the proposal be followed. As new potential uses of the imagery arise, the investigators will cooperate with and advise those interested in the

use of the imagery. In general a broad spectrum of people must be involved in gathering data and interpreting it.

Investigation Title: Utilization of ERTS-A Data in Geological Evaluation, Regional Planning, Forest Management, and Water Management in North Carolina

Proposal No. 18

GSFC ID No. UN 281

Contract No. NAS5-21732

Principal Investigator: Charles W. Welby

5. Marine Resources and Ocean Surveys

F. Estuary Dynamics

ERTS-1 images 1133-15150 and 1205-15150 show the response of the water masses in Albemarle and Pamlico Sounds to winds. In 1133-15150 the water and the suspended matter in it are pushed northward in response to a wind flow from out of the south. In 1205-15150, the water and the suspended matter is pushed southward in response to a flow of air from the north and northeast.

Variations of concentration of suspended matter also appear in the imagery, and the imagery could be used to guide sampling and interpretation of the data.

Image 1205-15150 is believed to show the presence of a phytoplankton bloom in Albemarle Sound and along the Pamlico River.

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3. Mineral Resources, Geological Structures, Landform Surveys

I. Landform Surveys

Major physiographic units of the North Carolina Coastal Plain are recognizable on images 1081-15262, 1170-15205, and 1134-15211. Among matters of interest are that the several scarps (ancient shorelines) are recognizable and traceable, that the relationship between a possible Pleistocene lagoon and the present drainage can be recognized more readily on the ERTS-1 image than on previously available imagery, that the Pleistocene and Holocene geology can be seen to be controlling agricultural development, and that the boundary between two Cretaceous formations marks the boundary between areas of differing intensity of agriculture.

The boundary between the Triassic Basin and the metamorphic and igneous rocks of the Piedmont can be discerned in places, partly on the basis of land-use patterns and partly by interpretation of structural trends visible on the imagery.

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7. Environment

C. Lake and River Pollution Surveys

Sediment influx into High Rock Lake of the central Piedmont and Buggs Island Lake and Lake Gaston on the North Carolina-Virginia border in response to heavy rainfall upstream has been documented in ERTS-1 imagery (image no. 1080-15201). The Nutbush Creek area of Buggs Island Lake extending southward toward Henderson, North Carolina, contains a smaller amount of suspended sediment and appears darker on the image than those parts with a greater amount of suspended matter. This fact speaks to the level of land exposed to erosion in this area.

Along the Yadkin River, upstream from High Rock Lake, numerous open areas which are possible sources of sediment can be recognized. ERTS-1 image 1046-15313 shows the sediment load entering High Rock Lake following a major rainstorm. Gaging data at Yadkin College show the passage of the suspended load.

At New Bern, North Carolina, the estuary of the Neuse River acts as a sink for load carried by the river. In addition, the flow of the Trent River entering the Neuse at New Bern maintains its identity for some distance along the south bank of the Neuse. This relationship is well displayed on image no. 1205-15153. Knowledge of this relationship should guide an on-going sampling program being conducted by the University's Pamlico Marine Laboratory as well as one by the Office of Water and Air Resources.

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5. Marine Resources and Ocean Surveys

B. Survey of Current and Ocean Dynamics

Images 1078-15034, 1132-15092, 1132-15094, 1133-15150, 1205-15150, all show the effects of wind and tidal stage upon sediment transport in North Carolina coastal waters. Of especial interest is the long plume extending 60 to 70 miles to sea northeastward from Cape Hatteras. This feature is believed to have developed in response to winds from the south and southwest (image 1132-15092) along with effects of the Gulf Stream. Nearshore drift and plume development through the inlets in the barrier islands for the various wind and tidal conditions show the sensitivity of coastal North Carolina waters to wind effects.

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1. Agriculture/Forestry/Range Resources

H. General

ERTS-1 imagery enlarged to a scale of 1:300,000 is very useful in recognizing bare land within forested areas. This fact permits use of the imagery for monitoring clear cutting and to monitor and display for governmental managers the extent to which urbanization is removing forested areas across North Carolina. Openings in forests as small as five acres have been recognized on MSS band 5 imagery at this scale.

In the Coastal Plain, clearing and drainage of low-lying areas for development of tree plantations can be monitored. The cleared, but still undrained areas stand out particularly well on bands 6 and 7. Images 1080-15203 and 1134-15211 show the activity of a major timber producer south of Lake Waccamaw, North Carolina.

Patterns of soil groups also stand out, and wet, organize soils with shallow, nearly impervious layers appear as lighter areas on the imagery, especially in bands 5 and 6.

ERTS-1 IMAGERY AS AN AID TO GEOMORPHIC INTERPRETATION OF THE CAROLINA COASTAL PLAIN

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GSFC ID No. UN 281
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Presented at North Carolina Academy of Science
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ERTS-1 imagery of the Coastal Plain near the North Carolina-South Carolina border allows a partial interpretation of the sequence of events which led to the development of the geomorphic elements of the area. The interpretation of the events is not original but an attempt has been made to add to them by use of small-scale ERTS imagery which provides a regional view that is lacking in conventional aerial photographs. The study area extends approximately from the Cape Fear River of North Carolina to the Lynches River in South Carolina. The various features are described in the order in which they are encountered in moving from the Fall Line to the Atlantic Ocean.

The relatively dark area in the northwest corner of image 1081-15262 (Fig. 1) is underlain by Triassic rocks and metamorphic rocks of the Piedmont. The lighter area just to the southeast is the sandy Cretaceous Tuscaloosa formation. Several light patches within the dark Piedmont rocks are outliers of the Tuscaloosa formation.

One of the most distinct features on the imagery is a northeast-trending sharp tonal break which corresponds approximately to the Orangeburg or Coates Scarp, and also to the contact between the Cretaceous Tuscaloosa and Black Creek formations. The Black Creek formation contains sands, clays, and marls. In the upper Coastal Plain, which contains the Sandhills region, floodplains are narrow and difficult to delineate.

Southwest of the Orangeburg Scarp is an area of relatively high reflectance. This area contains southeast-flowing subparallel streams with wide floodplains and has large and well developed Carolina bays. The difference in reflectances between the upper and middle coastal plain is probably due to the different amounts of land cleared for agricultural purposes, the Sandhills area being less suitable for agriculture. Forests have lower spectral responses than cultivated areas.

The Surry Scarp is the southeastern boundary of the middle Coastal Plain. It is mappable on ERTS imagery only as a subtle lineation on the Coastal Plain and is most notable south of the Lynches River in South Carolina where it forms a small embayment (image 1081-15262). The scarp trends northeastward approximately parallel to and west of the lower Little Pee Dee River, turns northward where it crosses the Little Pee Dee River and then parallels the Lower Lumber River and Big Swamp (Fig. 2, image 1170-15205). At Lumberton, North Carolina, the Surry Scarp again turns northeastward and crosses the Cape Fear River into the Bladen Lakes area.

Immediately southward of the Surry Scarp, southeastward flowing streams from the middle Coastal Plain abruptly turn to the south-southwest and form the lower parts of the Little Pee Dee and Lumber Rivers. In 1964, Johnson and DuBar suggested this area was a Pleistocene lagoon. Evidence from the ERTS imagery supporting their interpretation include: (1) the large width of the Lumber River and Little Pee Dee River floodplains as compared to the smaller floodplains of the larger Cape Fear River, and (2) the existence of ancient higher sediments within the modern floodplain. The sediments were probably deposited where the middle Coastal Plain rivers emptied into the standing water of the ancient lagoon. These areas of older sediments are currently being cleared for agriculture due to their slight elevation above the modern floodplains. The Pleistocene shoreline prograded eastward from the ancient lagoon forming a sequence of beach ridges near Conway, South Carolina. The Walterboro Scarp is the southeastern limit of this extensive area of beach ridges. The scarp crosses the Pee Dee River near its junction with the Lynches River (image 1081-15262) and continues northeastward, passing west of Lake Waccamaw (image 1170-15205), one of the larger Carolina bays.

Green Swamp appears as a roughly circular, vegetated depression partially encircled on the south and southwest by low broad ridges (Fig. 3, image 1134-15211). The swamp may have been a Pleistocene lake which was breached in the southwest and drained by the Waccamaw River.

Southeast of the Green Swamp, a large wedge-shaped area of the Coastal Plain extends from the Cape Fear River southwestward to the Waccamaw River. This probably represents sediment swept southward by littoral drift from the Cape Fear River. The mouth of the Cape Fear River has also been deflected southward, and barrier islands have developed eastward of its lower course. Broad, low, beach ridges trend northeast toward the river. Details of the classic cuspate spit at Cape Fear are visible on the ERTS imagery. The large square disturbed area near Southport, North Carolina, is the construction site of a nuclear power plant. The future route of cooling water pipelines can be traced southward to the Atlantic Ocean (image 1134-15211).

References

Johnson, H. and DuBar, J., 1964, Geomorphic elements of the area between the Cape Fear and Pee Dee Rivers, North and South Carolina: Southeastern Geology, V. 6, p. 37-48.

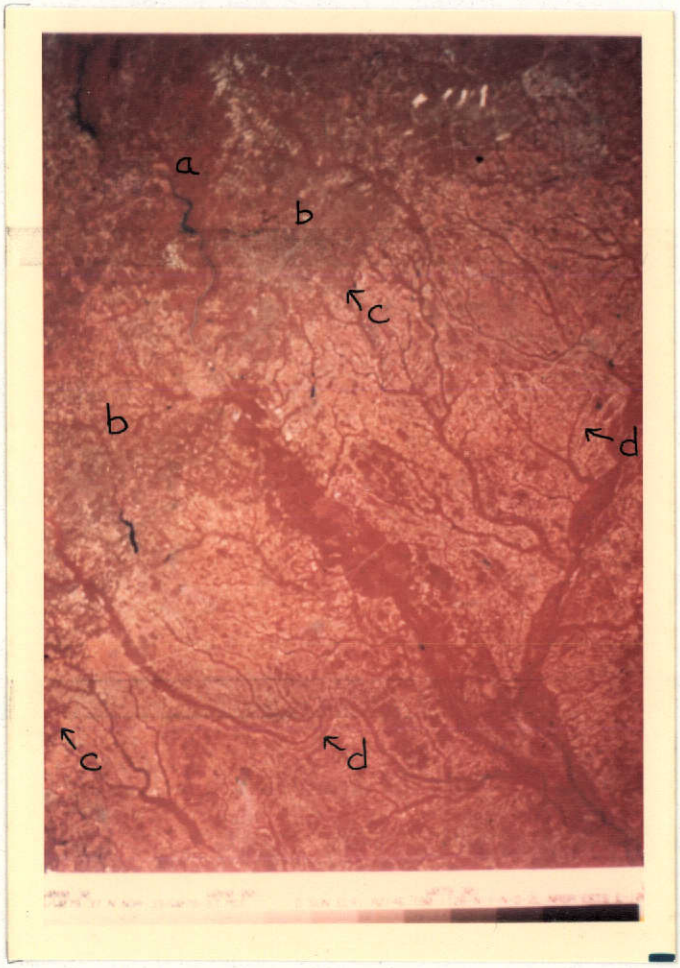

Figure 1. Image No. 1081-15262

a. Piedmont Rocks

b. Tuscaloosa Formation

c. Orangeburg Scarp

d. Surry Scarp

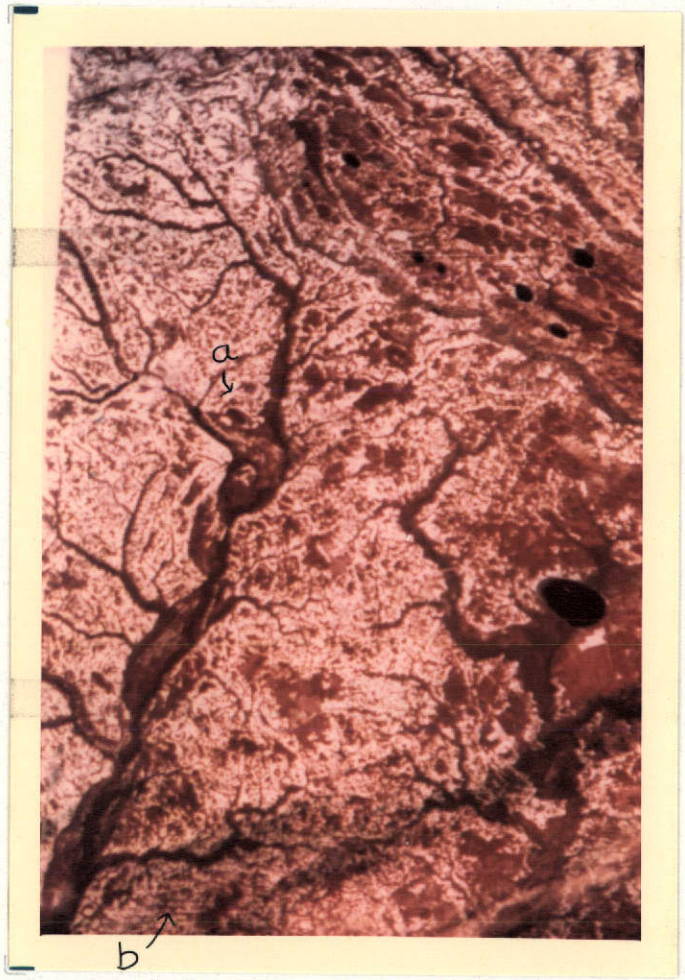

Figure 2. Image No. 1170-15205

a. Surry Scarp at Lumberton, N. C.

b. Beach ridges near Conway, S. C.

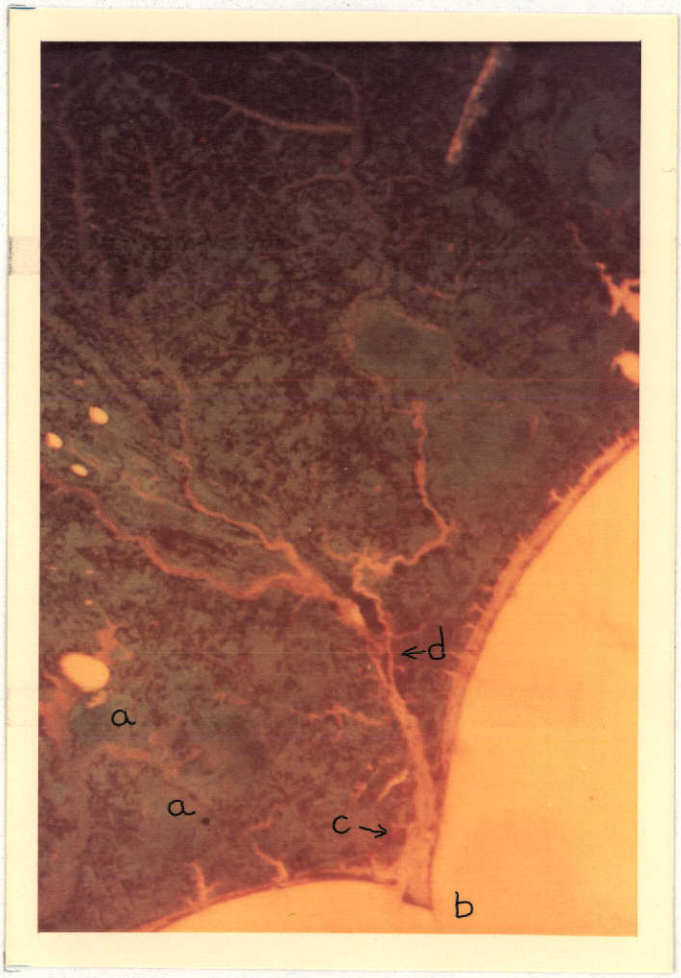

Figure 3. Image No. 1134-15211

a. Green Swamp

b. Cape Fear

c. Nuclear Power Plant Site

d. Wilmington, N. C.

TIME-LAPSE IMAGING OF COASTAL PROCESSES -

A VIEW FROM SPACE

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Presented at North Carolina Academy of Science
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Introduction

Mairs in his 1970 paper analyzed Apollo 9 photographs of the North Carolina coast and demonstrated the usefulness of space imaging in the interpretation of certain coastal processes. The present paper arises from the availability of repetitive satellite coverage from the NASA ERTS-1 satellite, and the discussion concentrates upon relating water-sediment dynamics to wind direction and tidal stages. It is a progress report, describing some of the changing coastal scene. Hopefully, it will give a regional perspective to some of the papers that are to follow.

Technique

ERTS-1 returns imagery in four bands from a multispectral scanner: 0.5 to 0.6; 0.6 to 0.7; 0.7 to 0.8; and 0.8 to 1.1 microns. Colloquially, these are the green, red, near infrared, and farther infrared bands, or are known by their NASA designations as bands 4, 5, 6, and 7, respectively. Neither of the infrared bands are in the thermal part of the spectrum. Band 6 reportedly responds best to chlorophyll.

The satellite is on a polar orbit and a 103 minute cycle at an altitude of 564 miles. Images are taken over a given spot every 18 days between 10 and 11 a.m. EST for North Carolina. Thus the images of a given locality are taken with the same sun angle except for seasonal variations.

The 70 mm black and white positive transparencies received from Goddard Space Flight Center are placed in a color additive viewer. The operator permits a different color of light to pass through each of the transparencies representing the four bands of the spectrum. By manipulating the color of light through each band and the intensity of the light the operator can bring out subtle differences and features in the imagery as well as emphasize features readily seen in the black and white transparencies. Bands 4 and 5 record best the suspended materials in a body of water, and bands 6 and 7 record near-surface phenomena. The individual scene is 100 nautical miles on a side.

The mode of presentation will be to show the North Carolina coast as viewed by ERTS-1 on several occasions and to discuss briefly what the imagery displays. Wind and tidal data will be presented in a series of slides.

Time has not permitted detailed analysis of current velocities and coastal hydraulics as they relate to the imagery. However, Mairs (1970) has pointed out that once plumes related to ebb flow are sufficiently beyond the inlets to overcome the characteristics of a jet, their travel pattern is strongly influenced by the winds and currents active in the area.

The availability of National Weather Service maps in the Department of Geosciences has greatly facilitated compilation of the climatological data. Maps for surface conditions are available for 0100 and 1300 hours EST, and these maps make possible determination of not only local wind patterns and velocities but also the general wind patterns and velocities away from recording stations.

Direction of tidal flow and the fraction of the tidal cycle are indicated by symbols as is the wind direction. Wind velocities are 10 knots or less unless otherwise indicated. Probably offshore the winds were in the neighborhood of 25 to 30 knots in some instances just prior to a satellite pass or at the time of the pass.

Imagery

The first slide is the famous Apollo 9 view of the North Carolina coast taken at 10:01 EST, March 12, 1969, following a period of 7 to 10 knot northwest winds and at approximately 72 percent of the way into the ebb tide. Mairs (1970) calculates that a particle in Ocracoke Inlet at the beginning of the ebb tide would be 7.7 nautical miles outside the inlet at the time the photograph was taken.

The first good ERTS imagery of the Albemarle Sound-Manteo area is found in image 1078-15084 of October 9, 1972. The tide was about one-third of the way into its ebb cycle; no wind data are available at the present time. Image 1078-15084 shows a general diffuse band of sediment parallel to the shore, and internal structures indicate a southward drift.

At the time of a December 2, 1972, pass, as well as for several days before, the wind had been blowing out of the west and southwest. At the time of the pass a northeastward moving high pressure area was centered over the North Carolina coastal area. The tidal stage was about eight-tenths of the way toward full ebb.

ERTS-1 image 1132-15092 of December 2 shows the effect of the currents and wind upon the plumes from earlier tidal cycles, and it is believed that the strong northeastward stretching of the plume from Cape Hatteras shows the control of the Gulf Stream as well as the effects of surface winds. At the latitude of Cape Hatteras the Gulf Stream is about 20 miles offshore.

Within Pamlico Sound the suspended sediment shows recognizable patterns as does the sediment in the eastern end of Albemarle Sound. Of particular interest is the tongue of turbid water extending southward on the east side of Roanoke Island.

Image 1132-15094 was taken 2 seconds after image 1132-15092. The effects of the northeastward blowing winds and associated currents on earlier ebb tide plumes is clearly evident as are the characteristic ebb tide plumes passing through Hatteras and Ocracoke Inlets. The current pattern about Cape Hatteras is better seen in this image than in the preceding one.

On December 3 the satellite imaged the whole of Albemarle and the greater portion of Pamlico Sound. The tidal stage was about three-quarters of the way toward ebb. At the time of the pass the wind was blowing from the southwest at about 7 to 10 knots. ERTS-1 image 1133-15150 shows the turbid waters of Albemarle Sound and Pamlico Sound pushed northward in response to the wind effects. The tidal delta in Oregon Inlet shows, and the ebb tide plumes of Hatteras Inlet and Ocracoke Inlet are being shoved northeastward in response to the wind effects. The prominent southward-trending line extending from near the center of the north edge of the image is the Suffolk scarp.

Again, on the 25th and 26th of January ERTS-1 obtained satisfactory images of the Manteo-Cape Hatteras region. Winds during this period were dominantly out of the northwest, and the tides were about halfway into full flood. Winds of 20 to 30 knots were present offshore on the 24th and on the 25th following the pass of the 25th, and probably were present at the instant of the pass.

Image 1186-15090 of the Manteo area reflects the flood tidal cycle with little plume-form turbidity patterns around the inlets, and only faint suggestions of coastwise turbidity. The suspended sediment flushing from Pamlico Sound can be recognized. As in the case for the December images a northeastward-trending sediment plume is found off Cape Hatteras. This plume shows up best in band 4, suggesting that much of it lies several tens of feet below the surface. Non-turbid water in Ocracoke Inlet can be observed, delineating the pattern of the flood tide flow.

Thin scattered clouds make interpretation of the January 26 image of the Albemarle Sound-Pamlico Sound area difficult. However, the tidal and wind effects seem to be the same as for January 25, although the turbidity of the water in Albemarle Sound appears in a patchy distribution.

On February 12 and 13 the satellite crossed the Manteo-Cape Hatteras region again. Cloud cover interfered with imaging on the 12th, but an image of Albemarle Sound to Pamlico Sound was obtained on the 13th (1205-15150). This image was made two days after a snowstorm which crossed the area on February 10. Of particular interest in this image

is the presence of turbid water thrust southward by the north-northeasterly winds. The tide had just turned from ebb to flood, and thus the view is essentially one of slack water at the end of ebb tide.

At this time of the year, significant phytoplankton blooms occur on the Pamlico River and in Albemarle Sound. Because the turbid water seldom reflects in bands 6 and 7 and because there appears to be significant reflections in band 6 and faintly in band 7 from the Pamlico River area and Albemarle Sound, it is believed that this image records the presence of the phytoplankton blooms. Because of the cloudiness on the January 26 image it is impossible to determine whether a possible phytoplankton bloom was imaged at this time.

Longshore effects of the northerly winds as well as the circulation patterns in Pamlico Sound and Albemarle Sound can be observed.

A strip of the coast centering on Cape Lookout was imaged with varying degrees of success on October 10 and November 15, 1972, and February 13, 1973. No wind data were available for the October 10 pass (1179-15195) and clouds covered the Cape itself. However, the tide was at one-quarter ebb. The most dominant feature of this image is the apparent southward movement of turbid water from Swash Inlet and Ocracoke Inlet and the streamlines in the turbid water at the southern end of Pamlico Sound. Small ebb plumes are recognizable in the inlets south of Cape Lookout.

Image 1115-15152 taken on November 15 shows a mushroom shape to the sediment around Cape Lookout. At the time of the imaging the tide was about 40 percent toward maximum flood and the wind was from the northwest.

The general diffusion of suspended materials in Core Sound as well as wispy remnants of ebb tide plumes from the inlets south of Cape Lookout can be detected in this image. North of Cape Lookout, the ebb tide plume from Ocracoke seems to be drifting southward.

During December and January the Cape Lookout area was more than 50% cloud-covered during the ERTS-1 passes. On February 13 imagery was obtained which shows some interesting features. The winds the day prior to the pass were out of the north. At the time of the pass the winds were calm. The tide had just turned to flood, as is indicated by the slide. For New Topsail Inlet the image was taken within a minute of the calculated tidal change.

Image 1205-15153 (with blue in band 7) shows well the boundary between the marshlands and the higher areas at Core Banks and elsewhere. Cloud wisps obscure the details of plume behavior at Swash Inlet north of Cape Lookout, but the streamer south from the latitude of Swash Inlet suggests that the winds offshore have paralleled those on shore and have promoted a southward surface drift. The ebb tide plume

through Drum Inlet north of Cape Lookout is a prominent feature, reflecting the jetting effects associated with the ebb tide just concluded.

When bands 4 and 5 are viewed separately, either with color added or in the black and white format, seaward banding of the turbid waters can be defined off Cape Lookout, apparently recording earlier masses of turbid water which are diffusing into the open Atlantic.

The shoals off Cape Lookout are readily recognizable, and their control on water circulation the Cape can be studied by comparing a sequence of images and correlating the patterns seen with weather and current information.

Bands 6 and 7 are very useful for delineating flooding. The moisture-rich soils of the floodplains show as dark areas alongside the rivers for a short period after flooding, and in those areas where the water is actually present, the water is dark in the images of these bands. Comparison of images 1080-15203 and 1134-15211 from October 10 and December 4 shows the extent of flooding along the Cape Fear drainage following extensive late November rains. The October 10 image shows the drainage with the rivers well within their banks; the December 4 image shows the extent of flooding along the lower Cape Fear River and is a reflection of the increased moisture content of the alluvial soils following flooding.

Conclusion

This tour of the North Carolina coastal area, although not based on true time-lapse photography, has permitted a broad view of coastal processes; hopefully demonstrated some of the uses of ERTS-1 type data; and perhaps has suggested other uses for the imagery. With a more comprehensive study of weather and current information together with the information that can be extracted from the imagery, one can probably develop a more detailed understanding of the behavior of the water masses off the coast of North Carolina. It is my belief that with detailed study of ERTS and related data we can formulate better models of coastal processes and water mass behavior, and we can fit some of our more detailed investigations into a more solid framework than we have been able to do heretofore.

References

Mairs, R. L., 1970, Oceanographic interpretation of Apollo photographs: Photogr. Engr., V. 36, p. 1045-1058.

THE NORTH CAROLINA ESTUARINE-SHELF COMPLEX - PLEISTOCENE TO RECENT HISTORY

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A high resolution boomer study of the Pamlico River and part of Pamlico Sound, North Carolina, reveals a Pleistocene history begun by filling of pre-Pleistocene channels when the margin of the sea followed the Suffolk Scarp. Two broad interruptions in sedimentation during the Pleistocene-Holocene interval are indicated by channeling and backfilling. The character of the sedimentation as revealed in the geophysical records suggests open water sedimentation. In the upper 20 feet or so of the section the geophysical records are interpreted to indicate less current activity than lower in the section. This change is believed to reflect the appearance of the present barrier islands or their antecedents and formation of Pamlico Sound. Subsurface channels in and near Ocracoke Island suggest that the Ocracoke Inlet area has served as a funnel through which tidal currents and/or streams have passed since the first Pleistocene sediments were deposited.

Imagery obtained from ERTS-1 provides an overview of the North Carolina coast, permitting better visualization of the present estuary-shelf relationship. Sediments stirred up in shallow Pamlico Sound are carried out through the inlets as plumes. Longshore drift patterns are also recognizable, and the general diffusion of sediment along the coast is well documented. Earlier barrier systems either seaward or inland from the present coast must have functioned similarly.

Prior to the Holocene much of the North Carolina coastal area must have been open shelf, but for brief intervals exposed or shoal enough to permit extensive channeling. Barrier islands appeared with the advent of the Holocene, trapping behind them much of the fine material transported from the Piedmont and Coastal Plain. ERTS-1 imagery shows how the fines are transported seaward and the extent to which this transportation takes place. Studies are underway in an attempt to determine from the ERTS-1 images the amount of sediment moving through the inlets.